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TRIBOLOGICAL PROPERTIES ON ALUMINIUM (LM25) REINFORCED WITH BORON CARBIDE AND TUNGSTEN CARBIDE

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ABSTRACT

The major driving force in an automotive industry is to develop & implement the new materials for the reduction of mass, fuel consumption & vehicle emissions. Some automotive parts like engine cylinder, connecting rods, pistons & brake system are not satisfactory in Tribological properties, making increase in wear loss & decrease in hardness of the materials. Recently, Hybrid Metal Matrix Composites have evolved alternative to MMC. Hybrid Metal Matrix Composites are the composites having more than one reinforcement particulates. The main advantage of this type of composites can withstand high temperature; high wear resistance compared to MMC. Aluminium based Hybrid Metal Matrix Composites are widely used in automotive applications because of their good potential characteristics. In the present work, Hybrid Aluminum Metal Matrix Composite samples are fabricated by base metal Aluminium (LM25) reinforced with Boron Carbide (B_4C) of different weight percentages like 1.5%, 3%, 4.5% & Tungsten Carbide (WC) of constant weight percentage 1.5% by varying stirrer speed (200, 250 & 300rpm) by using Stir Casting method. Evaluation of Tribological properties of the composite samples is studied. Microstructure examination was done using Scanning Electron Microscope (SEM) to obtain distribution of B_4C & WC particulates in Al (LM25) matrix.

KEYWORDS: Aluminium (LM25), Boron Carbide, Tungsten Carbide, Wear Test & Stir Casting

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Original Article

1. INTRODUCTION

Hybrid composites, primarily consist of one matrix and two or more reinforcement. Hybrid Composite materials are produced by reinforcing two or more materials of varying properties with matrix phase. Various processing routes have been in use for the fabrication of HMMCs. Selection of a proper processing technique for the fabrication of HMMCs is very important, since the properties and cost are determined by the used fabrication method. The processing routes can be classified based on the state of the matrix, i.e., whether it is in liquid or solid or vapor state during processing. Generally, the fabrication of aluminium based HMMCs was done using Stir Casting method. In general, the major advantages of Hybrid metal matrix composites over monolithic materials e.g. iron, steel and other non-ferrous common metals are :High specific strength, High specific stiffness, Higher elevated temperature strength, Improved wear resistance, Low density, High strength to weight ratio, Improved damping capabilities, Good Thermal expansion coefficients. The main objective of the present work is

- To use the concept of Hybrid composites & improve characteristic properties in the automotive parts.
- Fabrication of Hybrid Al metal matrix composites by reinforcing Boron Carbide (B_4C) & Tungsten Carbide (WC) using Stir Casting process.

- To Conduct the Experimentation on Wear test & evaluate the Wear rate, Wear resistance & Co-efficient of friction.
- Analyze the microstructure behavior and to study the change in material properties of fabricated composite samples.

2. LITERATURE SURVEY

J. Hashim et al., [1], investigated on production of metal matrix composites by Stir Casting method was done. Considering Stir casting process variables like stirring speed, temperature, and impeller size were taken consideration during the process. Impacts of mechanical properties are determined by the reinforcement distribution, weight fraction, level contact with the matrix material. Stir casting method procedure is studied & factors affecting the process are investigated. Ulhas. K. Annigeri et al., [2], investigated on fabrication of aluminium metal matrix composite procedure by stir casting. The major problem of stir casting is to obtain sufficient wetting of particulates with the liquid molten metal, this can be solve by studying the variation of furnace temperature, stirring time, stirring speed effects during the processing were studied. Keshavsingh et al., [3], investigated on aluminium alloy LM25/B_4C composites are fabricated & studied the characterization of mechanical properties. Increase in weight % of B_4C particulates increases Ultimate tensile strength, hardness & impact strength. In the study 7% B_4C by weight fraction of fabricated composites provides the high strength & hardness. Siddesh Kumar N. G et al., [4], studied on mechanical & wear behavior of aluminium metal matrix hybrid composites were studied. The study evaluates the fabrication of Al2219 reinforced with B_4C using stir casting technique. The composite test specimens were experimented for tensile, density, dry sliding wear & microstructure tests. The density is relatively low & as compared with the fabricated composite samples. SEM results showed the fracture surface of tensile test specimens. M. Vamsi Krishna et al., [5], investigated on SiC/Gr reinforced hybrid particulate aluminium composites with different weight fractions were fabricated, at 15wt% the tensile strength is observed 192.45 MPa compared with the base matrix aluminium alloy. The microstructure study observed the uniform distribution of reinforcement particles in fabricated composites. V. Jaya Prasad et al., [6], investigated on Aluminium metal matrix composites with SiC reinforcements are produced by Stir Casting process, successfully. Fabricated composite samples are machined & studied the microstructure & tribological properties. To study the microstructure & tribological properties, the fabricated samples are subjected to mechanical tests like tensile test & hardness test are conducted. The SEM micrographs showed the uniform distribution of reinforcement with matrix. K. R. Padmavathi et al., [7], investigated on Aluminium Hybrid metal matrix composite were fabricated & studied the tribological behavior for the structural applications like aircraft & automotive industries. To study the tribological behavior, wear test was conducted using Pin-on-disc apparatus. The wear test shows the decrease in weight loss & wear rate with increase of % of reinforcement particulates. T. Hariprasad et al., [9], investigated on Wear Characteristics ofB_4C and Al_2O_3Reinforced with Al (5083) Metal Matrix based Hybrid Composite was studied. The microstructure SEM analysis showed the interfacial bonding between the B_4C and Al_2O_3 with the aluminium metal matrix. The hard carbide in B_4C increases the hardness & provides the high wear resistant property. 10% weight fraction the B_4C and Al_2O_3 with the aluminium showed the very good wear characteristics. Blaza Stojanovic et al., [10], investigated on the application of aluminium hybrid composites in automotive applications was studied. In the study, hybrid composites provide high performance vehicles with good tribological & mechanical properties. Instead use of steels for making car elements, aluminium hybrid composites total car mass of 2-2.5 kg was reduced. Reduction of vehicle mass resulted in reduction of fuel consumption by 5-7%.

In the present work, Hybrid Aluminum Metal Matrix Composite samples are fabricated by base metal Aluminium (LM25) reinforced with Boron Carbide (B_4C) of different weight percentages like 1.5%, 3%, 4.5% & Tungsten Carbide (WC) of constant weight percentage 1.5% by varying stirrer speed (200, 250 & 300rpm) by using Stir Casting method. Evaluation of Tribological properties of the composite samples is studied.

3. MATERIAL SELECTION

3.1. Materials Selection

The material selection is an important task for the work. For composite preparation, two types of materials to be selected, first is matrix material and second is reinforcing materials.

3.1.1. Matrix Material

Aluminium (LM25) casting alloy is selected as a matrix material. The chemical composition of Al (LM25) is shown in below table 3.1. It is the most abundant metal, most versatile & least expensive. It is extensible used in civil, automobile and aviation sector. Aluminium (LM25) has a very good finishability, wear resistance & excellent weldability. Figure 3.1 shows the Al (LM25) casting alloy ingots.

Figure 3.1: Al (LM25) Casting Alloy Ingots.

Table 3.1: Chemical Composition of Al (LM25) Casting Alloy

Composition	Si	Cu	Fe	Mn	Mg	Cr	Ti	Ni	Pb	Al
Percentage (%)	7	0.1	0.5	0.3	0.4	0.05	0.1	0.1	0.1	Balance

3.1.2. Reinforcing Materials

Boron Carbide (B_4C)

Boron carbide is a very hard Boron-Carbon ionic ceramic material, which is commonly used in bullet proof jackets, tank armor & engine. It is the hardest material behind diamond. Boron carbide particulates reinforced with Al (LM25) provides a good wear resistance, high toughness & good resistance towards high temperature. For the purpose of our project 350 Mesh (44 Microns) size of B_4C is selected. Figure 3.2 shows the Boron Carbide particulates.

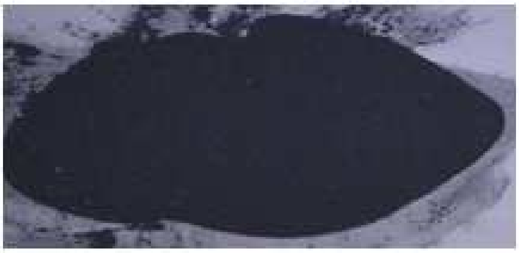

Figure 3.2: Boron Carbide Particulates.

Tungsten Carbide (WC)

Tungsten carbide is very hard & brittle material related to other metals. Tungsten Carbide is widely used in mining industries, cutting edges of drills & saws. Due to its high hardness characteristics, it has good wear resistance property. For the purpose of our project, 150 Mesh (105 Microns) WC size of WC is selected. Figure 3.3 shows the Tungsten Carbide particulates.

Figure 3.3: Tungsten Carbide Particulates.

3.2. Hybrid Al Matrix Composite Samples Composition

Table 3.2: Hybrid Al Matrix Composite Samples Composition

Sample no	Stirrer Speed (rpm)	Matrix	Reinforcement	
		Al (LM25) (%)	B_4C (%)	WC (%)
1	200	100	0	0
2		97	1.5	1.5
3	200	95.5	3.0	1.5
4		94	4.5	1.5
5		97	1.5	1.5
6	250	95.5	3.0	1.5
7		94	4.5	1.5
8		97	1.5	1.5
9	300	95.5	3.0	1.5
10		94	4.5	1.5

4. METHODOLOGY

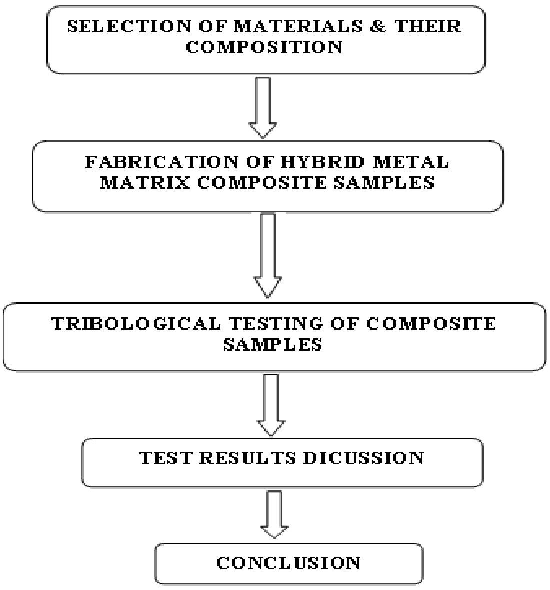

Figure 4.1: Methodology Flow Chart.

The methodology followed is shown in the flow chart in the above figure 4.1 Firstly, the materials should be selected based on their properties. Composition of reinforcement particulates were selected by studying the literature on Hybrid metal matrix composites. Fabrication of Hybrid Al metal matrix composites should be done by Stir casting method, using selected materials & their composition. The fabricated Hybrid Al metal matrix composites are to be tested for tribological evaluation by Wear test & SEM analysis. The tested tribological properties results are to be discussed.

5. EXPERIMENTAL TESTS

5.1. Tribological Test

5.1.1. Wear Test

The Wear behavior of the Hybrid Aluminium Matrix Composites was investigated using Pin on disc apparatus. Pin on disc Wear test machine is to determine the Co-efficient of Friction, Wear rate& Frictional force of material. ASTM G99 Standard specimens for wear test are shown in the figure 5.1.

Figure 5.1: Wear Test Composite ASTM G99 Standard Specimens.

5.1.2. Scanning Electron Microscopy (SEM) Analysis

Scanning electron microscopy is an electron microscope, which provides the microstructure images of worn wear test specimens. The microstructure of the worn surface can strongly influence the Hardness, strength, toughness & wear resistance properties. The method is done by scanning the worn wear test specimen’s surface with the high focused beam of electrons. The SEM analysis set up is shown in the figure 5.2.

Figure 5.2: Scanning Electron Microscopy (SEM) TESCAN Vega 3 LMU.

6. RESULTS AND DISCUSSION

6.1. Pin on disc Wear Test Tabular Column

Table 6.1

Sl no	Sample no	Stirrer Speed (rpm)	Sample composition	Tensile Strength (N/mm^2)	Yield Strength (N/mm^2)
1	1	200	Al (LM25)	168.1	150.9
2	2	200	Al (LM25)+1.5%WC+1.5%B_4C	156.5	136.4
3	3		Al (LM25)+1.5%WC+3.0%B_4C	173.3	152.5
4	4		Al (LM25)+1.5%WC+4.5%B_4C	182.2	158.1
5	5	250	Al (LM25)+1.5%WC+1.5%B_4C	152.81	142.81
6	6		Al (LM25)+1.5%WC+3.0%B_4C	181.98	88.33
7	7		Al (LM25)+1.5%WC+4.5%B_4C	196.95	164.33
8	8	300	Al (LM25)+1.5%WC+1.5%B_4C	174.97	154.71
9	9		Al (LM25)+1.5%WC+3.0%B_4C	186.64	168.80
10	10		Al (LM25)+1.5%WC+4.5%B_4C	201.97	169.05

Table 6.2: Pin on disc Wear Test Result

Sample No	Stirrer Speed (rpm)	Sample Composition	Weight of Specimen before Test W_1 (g)	Weight of Specimen after Test W_2 (g)	Weight Loss δW (g)	Density ρ (g/mm^3) $x10^{-3}$	Volume Loss (mm^3)	Wear Rate (mm^3/m)x 10^{-3}	Wear Resistance (m/mm^3)	Friction Force (N)	C.O.F (μ)
1	200	Al (LM25)	6.2815	6.25187	0.02963	4.1655	7.1131	5.927	168.70	3.86	0.1967
2	200	Al (LM25)+1.5%WC+1.5%B_4C	6.0875	6.06163	0.02587	4.0369	6.4083	5.340	187.25	3.94	0.2008
3		Al (LM25)+1.5%WC+3%B_4C	6.0866	6.06337	0.02323	4.0363	5.7552	4.796	208.50	4.06	0.2069
4		Al (LM25}+1.5%WC+4.5%B_4C	6.0715	6.05007	0.0214	4.0262	5.3226	4.435	225.47	4.19	0.2135
5	250	Al (LM25)+1.5%WC+1.5%B_4C	6.0793	6.05336	0.02594	4.0314	6.4344	5.362	186.49	3.90	0.1987
6		Al (LM25)+1.5%WC+3%B_4C	6.0714	6.04864	0.02276	4.0262	5.6529	4.710	212.28	4.02	0.2048
7		Al (LM25)+1.5%WC+4.5%B_4C	6.0913	6.06930	0.02199	4.0394	5.4458	4.538	220.35	4.11	0.2094
8	300	Al (LM25)+1.5%WC+1.5%B_4C	6.0712	6.04521	0.02599	4.0260	6.4533	5.377	185.95	4.24	0.2161
9		Al (LM25)+1.5%WC+3%B_4C	6.0763	6.05364	0.02266	4.0294	5.6236	4.686	213.38	4.44	0.2262
10		Al (LM25)+1.5%WC+4.5%B_4C	6.0693	6.04957	0.01973	4.0248	4.9021	4.085	244.79	4.69	0.2390

6.1.1. Pin on Disc Wear Test Result Discussion

Weight Loss Results Discussion

Variation of Weight Loss of Hybrid Al Metal Matrix Composites Wear Test Samples

The Weight loss of Hybrid Al metal matrix composite with different weight fraction of Boron Carbide & Tungsten Carbide at different stirrer speeds like 200, 250 & 300 rpm is tabulated in table 6.2& its variation is shown in the figure 6.1.

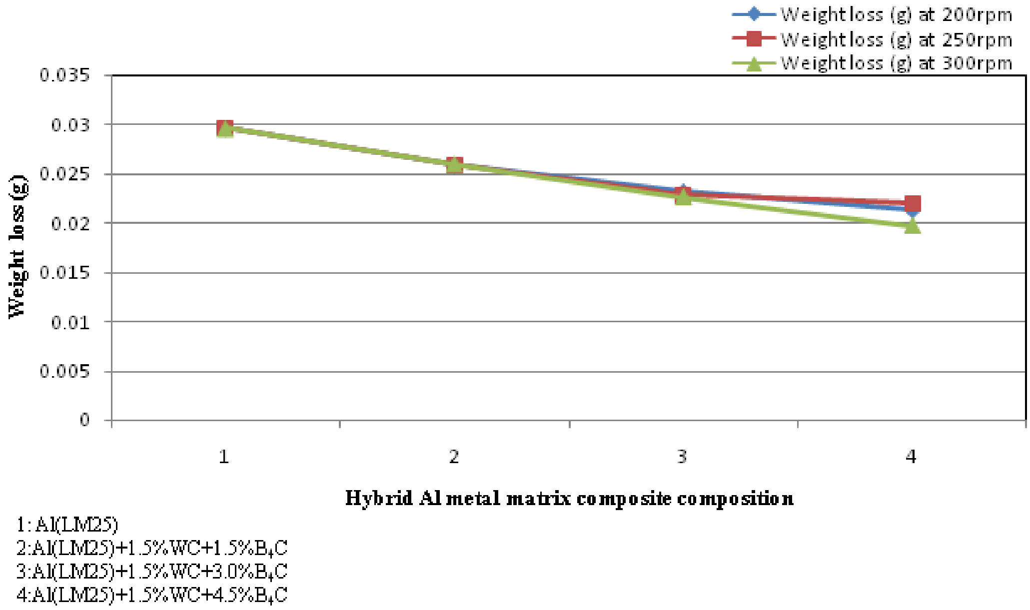

Figure 6.1: Graph of Weight Loss V/S Hybrid Al Metal Matrix Composites Wear Test Samples.

The Weight loss of Al (LM25) +1.5%WC+1.5%B_4C is 0.02587g at 200 rpm, 0.02594 at 250 rpm & 0.02599g at 300 rpm, Al (LM25) +1.5%WC+3% B_4C is 0.02323g at 200 rpm, 0.02276g at 250 rpm & 0.02266g at 300 rpm & Al (LM25) +1.5%WC+4.5%B_4C is 0.0214g at 200 rpm, 0.02199g at 250 rpm & 0.01973g at 300 rpm. The Wear loss of Al (LM25)+ 1.5%WC +4.5%B_4C at 300 rpm shows less weight loss compared to base metal Al (LM25) & other composition composite samples. The Wear loss of Hybrid Al matrix composite decreases with increase in weight % of 4.5% B_4C & 1.5% WC which makes decrease in density.

Wear Rate Results Discussion

Variation of Wear Rate of Hybrid Al Metal Matrix Composites Wear Test Samples

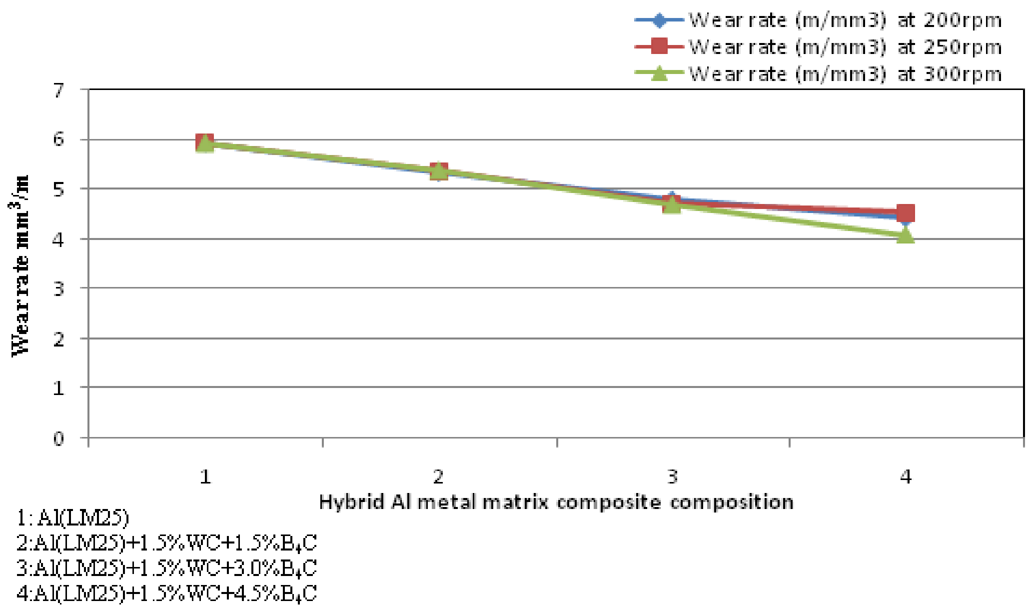

Figure 6.2: Graph of Wear Rate v/s Hybrid Al Metal Matrix Composites Wear Test Samples.

The Wear Rate of Hybrid Al metal matrix composite with different weight fraction of Boron Carbide & Tungsten Carbide at different stirrer speeds like 200, 250 & 300 rpm is tabulated in Table 6.1& its variation is shown in the Figure 6.2. The Wear Rate of Al (LM25) +1.5%WC+1.5%B_4C is 5.340 mm^3/m at 200rpm, 5.362 mm^3/m at 250rpm & 5.377 mm^3/m at 300ropm, Al (LM25)+1.5%WC+3.0% B_4C is 5.7552 mm^3/m at 200rpm, 5.6529 mm^3/m at 250rpm & 4.686 mm^3/m at 300rpm, Al (LM25)+1.5%WC+4.5%B_4C is 5.3226 mm^3/m at 200rpm, 5.4458 mm^3/m at 250rpm & 4.085 mm^3/m at 300rpm. The Wear Rate of Al (LM25) +1.5%WC+4.5%B_4C at 300rpm shows less Wear rate compared to base metal Al (LM25) & other composition composite samples. The Wear Rate of Hybrid Al matrix composite decreases with increase in weight percentage of 1.5% Tungsten Carbide & 4.5 % Boron Carbide particulates.

Wear Resistance Result Discussion

Variation of Wear Resistance of Hybrid Al Metal Matrix Wear Samples

The Wear Resistance of Hybrid Al metal matrix composites with different weight fraction of Boron Carbide & Tungsten Carbide at different stirrer speeds like 200, 250 & 300 rpm is tabulated in Table 6.1& its variation is shown in the Figure 6.3. The Wear Resistance of base metal Al (LM25) is 168.70 m/mm^3. The Wear Resistance of Al (LM25)+1.5%WC+1.5%B_4C is 187.25 m/mm^3 at 200rpm, 186.49 m/mm^3 at 250rpm & 185.95 m/mm^3 at 300rpm. The Wear Resistance of Al (LM25)+1.5%WC+3.0%B_4C is 208.50 m/mm^3 at 200rpm, 212.38 m/mm^3 at 250rpm & 213.38 m/mm^3 at 300 rpm. The Wear Resistance Al (LM25) +1.5%WC+4.5%B_4C is 225.47 m/mm^3 at 200rpm, 220.35 m/mm^3 at 250rpm & 244.79 m/mm^3 at 300rpm. The Wear Resistance of Al (LM25) +1.5%WC+4.5%B_4C at stirrer speed 300 rpm is having high wear resistance property compared to other composite samples. The Wear Resistance of Hybrid Al metal matrix composite increases with increase in weight percentage of 4.5 % Boron Carbide & 1.5 % Tungsten Carbide particulates due to hard carbide particles have capacity to resist towards wear.

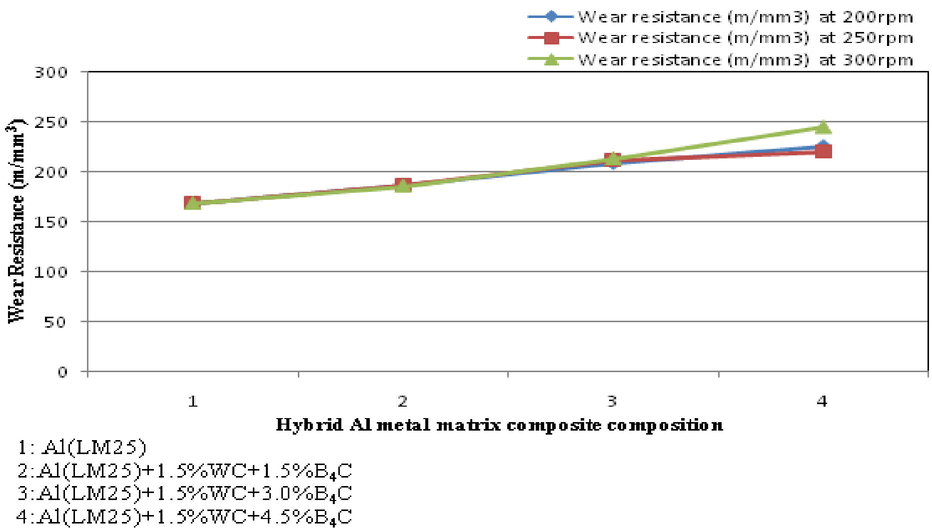

Figure 6.3: Graph of Wear Resistance v/s Hybrid Al Metal Matrix Wear Test Samples.

6.2 SEM Analysis Results & Discussion

Figure 6.4 shows, the typical SEM micrographs of Al (LM25) +1.5%WC+1.5%B_4C composites at stirrer speed of 300 rpm after the wear tests with magnification of 50µm, 100µm & 200µm. The SEM results shows, the wear debris, wedges, fracture & adhesive grooves.

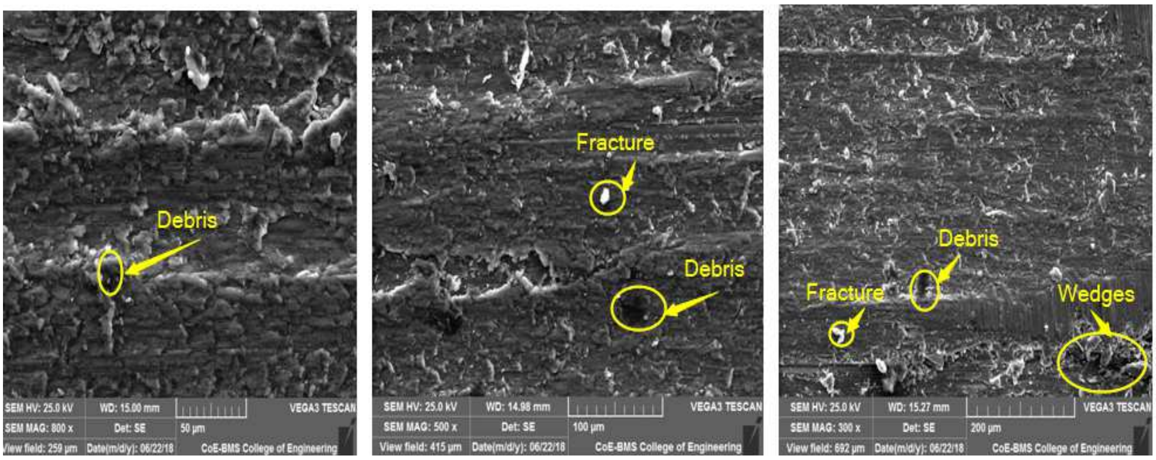

Figure 6.4: Typical SEM Micrographs of Al (LM25)+1.5%WC+1.5% B_4C Composite at Stirrer Speed of 300 rpm after the Wear Test.

There is low agglomeration & porosity. The grooves &ridges formed run parallel to the sliding direction. The grain refinement was seen, so the mechanical properties had been improved compared with base metal Al (LM25).

Figure 6.5 shows, the typical SEM micrographs of Al(LM25) +1.5%WC+3.0%B_4C Composites at stirrer speed of 300 rpm after the wear test with magnification of 50µm, 100µm & 200µm. The formation of grooves & ridges were observed running parallel to the sliding direction. The sliding direction of worn surfaces had been observed. The SEM results shows, the wear debris, fracture & plough. From the micrographs, it was observed that the wear voids, debris & plough were decreased as the increase in the 4.5% B_4C weight fraction of reinforcement in the composite wear samples.

Figure 6.6 shows, the typical SEM micrographs of Al (LM25) +1.5%WC+4.5%B_4C composites at stirrer speed of 300 rpm after the wear test with magnification of 50µm, 100µm & 200µm. From the micrographs, it is observed that the wear voids, debris & plough were decreased as the increase in the weight fraction of 4.5% B_4C reinforcement in the composite wear samples. The grain size of the Al (LM25) +1.5%WC+4.5%B_4Ccomposite was very fine compared to the Al (LM25) +1.5%WC+1.5%B_4Ccomposite. As per the metallurgical view, the grain refinement improved the mechanical properties because B_4C is grain refiner for the Al metal matrix composites.

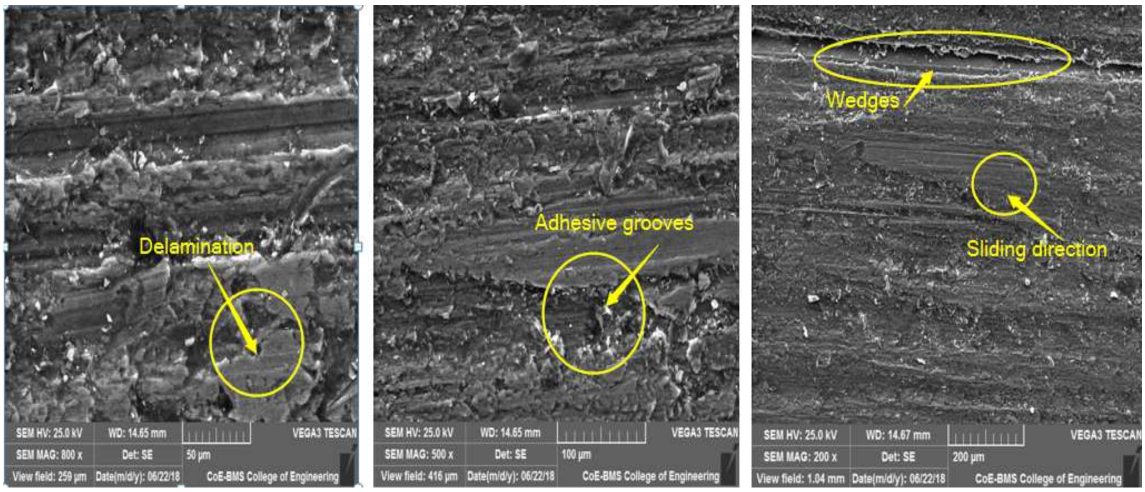

Figure 6.5: Typical SEM Micrographs of Al (LM25)+1.5%WC+3.0% B_4C Composite at Stirrer Speed of 300 rpm after the Wear Test.

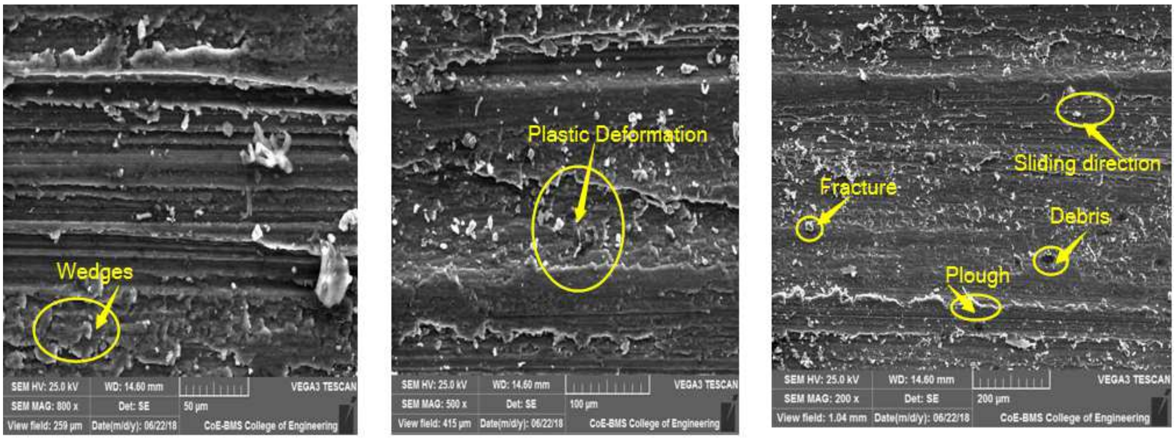

Figure 6.6: Typical SEM Micrograph of Al (LM25)+1.5%WC+4.5% B_4C Composite at Stirrer Speed 300rpm after the Wear Test.

7. CONCLUSIONS

- Hybrid Aluminium metal matrix composites were successfully fabricated by Stir casting method by varying stirring speed like 200, 250, 300rpm.
- In Wear test, Hybrid Aluminium metal matrix composites shows45.1% increase in wear resistancecompared to base metal Al (LM25)
- The SEM micrographs revealed that the homogeneous dispersion of B_4C&WC with Al (LM25)was observed.
- Al (LM25)+1.5%WC+4.5% B_4Ccomposite samples at stirrer speed 300 rpm shows high Tensile strength, Hardness & Wear resistance properties compared with base alloy & other composition samples of different stirrer speed. This shows Al (LM25) +1.5%WC+4.5% B_4Ccomposite samples at stirrer speed 300 rpm is the best Hybrid Aluminium metal matrix composites sample.
- Finally, the fabricated Hybrid Aluminium metal matrix composites shows the high tensile strength, hardness & wear resistance, so it is capable for the production of automotive parts like engine cylinder, pistons connecting rods & brake system.

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